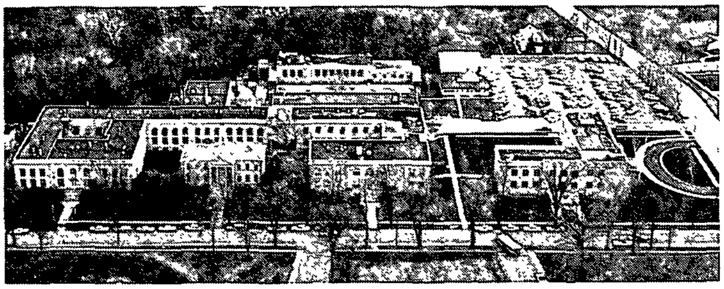

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IMPULSE DRYING OF LINERBOARD

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IMPULSE DRYING OF LINERBOARD

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ABSTRACT

Impulse drying, a process for drying paper in a long nip press with one heated surface, offers papermakers a new way to control product quality. Paper drying has, in the past, served to preserve the sheet quality built in the stock preparation, forming, and pressing processes. Impulse drying, however, can add substantially to sheet quality while performing the traditional drying role with lower energy demands and smaller equipment. This performance is possible because of the application of new dewatering and densification mechanisms to the drying process. When applied to linerboard, increases in density and tensile strength of 20 to 30% are possible, with water removal rates one hundred to one thousand times greater than in traditional dryer sections. Energy use is reduced, as up to one-half of the water removed is in the liquid phase. Impulse drying also has large effects on recycled fiber and high-yield pulp furnishes, and can make linerboard from these pulps with properties comparable to conventional kraft board. Process development is continuing with the construction of a laboratory pilot roll impulse dryer at The Institute of Paper Chemistry, under a grant from the Department of Energy. This pilot dryer will be used to demonstrate continuous operation and to provide large samples for conversion and printing tests.

KEYWORDS: Drying, pressing, linerboard, physical properties

INTRODUCTION

Conventional cylinder drying is accomplished using low-intensity temperature and vapor pressure driving forces, which limit both the rate of water removal and the extent of sheet quality development. Significant improvements in dryer performance will require finding new and much more intense dewatering and densification forces. Impulse drying is a new drying technology which introduces new mechanisms into the dewatering process, producing superior sheet properties with high water removal rates and low energy consumption.

Impulse drying is the process of removing water from a formed and partially pressed web in a press nip with one very hot roll. The original process concept was suggested by Wahren (1) in the late 1970's, and has been under development at The Institute of Paper Chemistry for the past five years, with a major experimental effort on the process during the past two years. The early work on this high intensity drying process has been described by Ahrens and Sprague (2) and by Arenander and Wahren (3).

Impulse drying typically utilizes pressures of 0.3-7 MPa (400 to 1000 psi), temperatures from 150-540°C (300 to 1000°F), and exposure times from 15 to 100 milliseconds. This brief exposure to intense conditions gives rise to dewatering and densification mechanisms which have not previously been applied to paper. These mechanisms have been described by Gottwald, Halsey and Williams (4), Sprague and Burton (5), and by Burton, Sprague, and Ahrens (6). High pressure steam is generated rapidly in the surface of the sheet next to the hot roll, and the movement of the steam acts to displace liquid water from the sheet into the felt. Sheet temperatures near the hot roll approach 200°C promoting fiber conformability and bonding within a few fiber diameters of the sheet surface. The middle of the sheet is preserved from excessive densification, as the pressure is released before the sheet is completely heated through and dried. Vapor flashing in the middle of the sheet restores a portion of the original sheet bulk. These processes result in a unique sheet structure allowing combinations of strength properties which are difficult to achieve in conventional papermaking. In addition, the rates of water removal are very high, with up to half of the water leaving in the liquid phase.

An overview of the perfomance of several commercially important paper grades after impulse drying has been presented by Sprague (7). The purpose of this paper is to present detailed information on the response of virgin kraft linerboard and several alternative linerboard furnishes to impulse drying.

EXPERIMENTAL

Equipment

The equipment used in this study was a bench-scale impulse drying simulator consisting of an electrohydraulic press (MTS) with one pressing surface electrically heated to an elevated temperature. This unit is shown in Fig. 1. The electronic control of the pressure-time profile can produce a variety of pressure pulses ranging from the typical bell-shaped profile of roll presses to the nearly rectangular pulse of extended nip presses. A load cell above the upper platen is used to control and measure the total load and profile. The heated platen temperature is controlled using a surface thermocouple signal to control power input to the electrical resistance heaters imbedded in the platen. A ring presteamer can be added to the system to preheat the sheets prior to impulse drying.

Handsheets

Handsheets are made according to TAPPI standard procedures, except that the sheet diameter has been reduced to five inches to permit high pressure drying within the dynamic force limits of the MTS system. Most of the linerboard studies were done with sheets of 125 g/m^2 weight (25 lb/1000 sq ft), but limited studies were also carried out at 205 and 337 g/m^2 (42 and 76 lb/1000 sq ft). Sheets are couched and lightly pressed to a high moisture content and stored in sealed plastic bags in cold conditions. Storage time is limited to two days. Just prior to drying, the sheets are prepressed to

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the desired moisture content in a laboratory roll press using press impulse levels typical of commercial equipment. This pressing procedure deviates from the standard, but is used to avoid excessive densification in the pressing step.

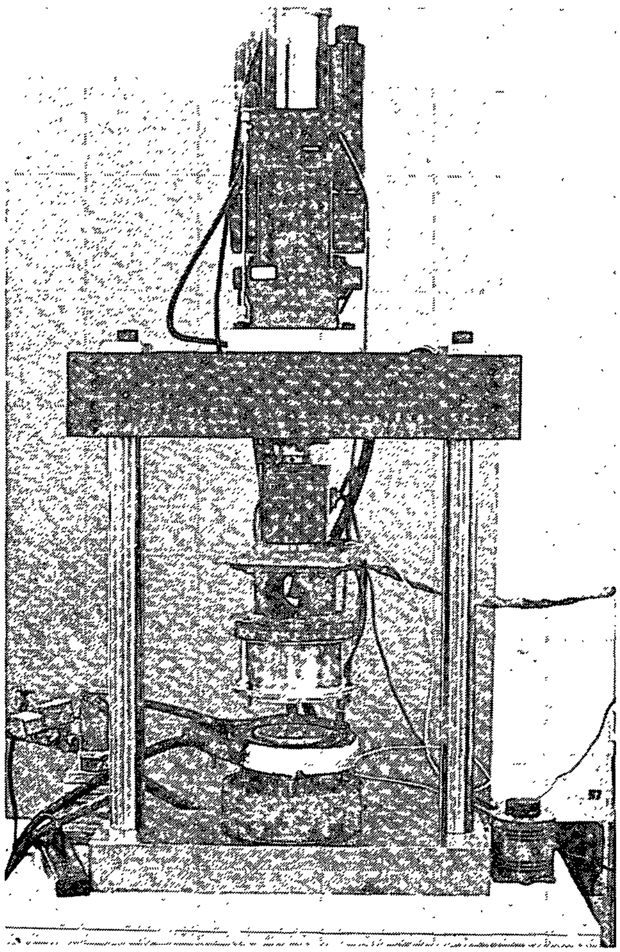

Fig. 1. MTS electrohydraulic press simulator with impulse drying head installed.

Impulse Drying

After prepressing, each sheet is weighed and then placed on a dry, conditioned wet press felt on the lower platen. The upper platen is then lowered under the control of the MTS system electronics to deliver the desired pressure pulse. The range of impulse drying conditions used in this study included 200 to 370°C (400 to 700°F), 2760 to 4830 kPa peak pressure (400 to 700 psi), and 15 to 30 milliseconds nip residence time. Impulse drying is usually used to remove only a part of the water originally in the sheet. Thus, immediately after impulse drying, the sheet is again weighed and then dried to approximately six percent moisture content between a dryer felt and a heated flat plate under conventional dryer conditions of about 3.5 kPa pressure (25 psi) and 115°C (290°F) temperature. The time required to reach the desired moisture target is determined by precalibration.

Once the sheets have been dried, they are conditioned according to TAPPI standards and subjected to a variety of physical property tests. The remnants from the tests are oven dried to get the dry weight needed for water removal calculations.

Control sheets for reference purposes are obtained by diverting a few handsheets from the impulse drying step and drying them entirely on the conventional drying simulator described above.

A flow chart summarizing the experimental test procedure is presented as Fig. 2.

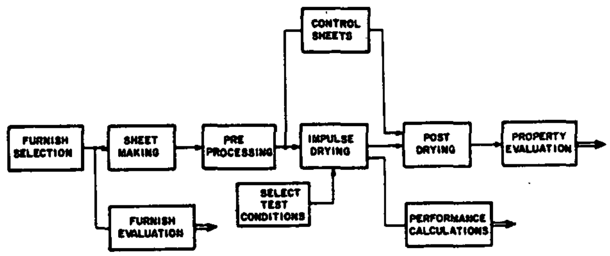

Fig. 2. Elements of performance evaluation.

Furnish

The furnish used in most of the linerboard studies was a virgin kraft, never-dried softwood pulp, lightly refined to 730 mL CSF. Several other alternative furnishes were studied, including recycled old corrugated containers and a sulfonated chemimechanical spruce pulp at 77 and 88% yield levels. The latter pulps were an experimental material chosen to study the potential of using impulse drying to develop the strength of high-lignin furnishes.

Energy Use Measurements

The heat required to impulse dry the linerboard sheets was determined using a lithium chloride tracer technique developed by Devlin (8). The method involves saturating the adsorption sites on the fibers with aluminum nitrate, then forming handsheets using a dilute aqueous solution of aluminum nitrate and lithium chloride. The sheets are then impulse dried as described above. The lithium chloride which was carried from the sheet into the felt by the flow of liquid water is recovered by extracting the felt in boiling water and analyzing the extract for its lithium content by flame emission spectroscopy. The liquid water flow to the felt can be calculated knowing the initial concentration of lithium in the handsheet. The impulse drying heat requirements can then be calculated from a simple energy balance. The sheets formed with lithium chloride were used only for water removal rate and energy use measurements; all physical property work was done on standard handsheets without added salts.

RESULTS

Water Removal Rates

Water removal rates in cylinder drying systems are typically below 25 to 50 kg water evaporated per hour per square meter of heat transfer surface (5

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to 8 lb/hr/sq ft). These low water removal rates result in a large surface area requirement for drying and, therefore, lead to large and costly equipment and buildings. Increasing water removal rates in the drying process is desirable from a capital cost standpoint. Impulse drying performs very well at removing water rapidly; the typical rates for linerboard are 100 to 1000 times those expected for cylinder dryers, as shown in Fig. 3 through 5.

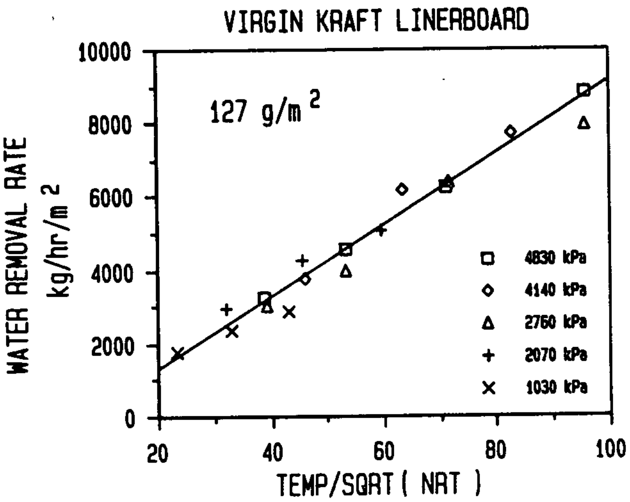

Fig. 3. Water removal rates for virgin kraft linerboard basesheet, 127 g/m^2. Data cover a range of pressures from 1030 to 4830 kPa, 260 to 370°C, and 34 to 127 milliseconds. All sheets initially at 21°C and 48% solids initially. TEMP = temperature, °C; SQRT(NRT) = square root of the nip residence time in milliseconds.

At any given sheet basis weight, solids content, and initial sheet temperature, the water removal rate is found to depend linearly on the hot surface temperature divided by the square root of the nip residence time. The tendency of water removal rate to decrease with increasing nip residence time occurs because most of the energy which effects water removal is introduced into the sheet in the first five to ten milliseconds of the impulse drying nip. Early water removal is dominated by vapor displacement and by wet pressing effects at low sheet percent solids, which are fast processes. Long nips work partially on dryer sheets and so display lower overall rates. The total water removal, however, increases gradually as the nip is extended beyond the initial contact period, leading to a decline in the measured water removal rate. Pressure has a minor effect on the rate of water removal for linerboard, as may be seen in Fig. 3.

The water removal rate can be further increased by preheating the sheet. Raising the sheet temperature from 21°C (70°F) to 82°C (180°F) by presteaming improves the water removal rate by about 50%, as shown in Fig. 4. This strong effect of sheet temperature is observed because a cold sheet will delay the initiation of the impulse drying mechanisms while it is warming up, making inefficient use of the available nip residence time.

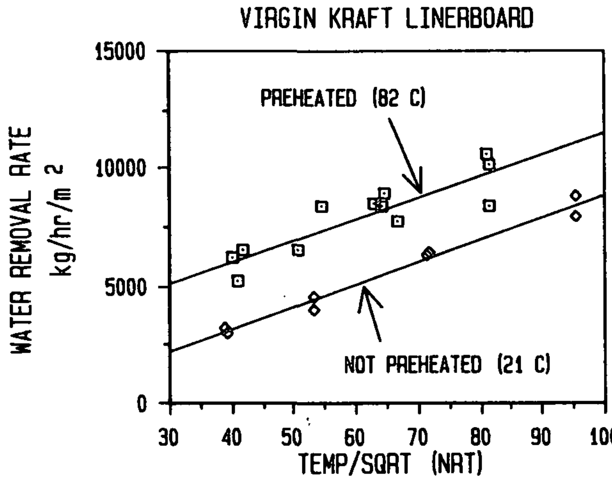

Fig. 4. The effects on water removal rate of preheating virgin kraft linerboard sheets from 21 to 80°C before impulse drying. TEMP = temperature, °C; SQRT(NRT) = square root of the nip residence time in milliseconds.

The moisture content of the sheet has a dramatic effect on water removal rates. Figure 5 shows the response of water removal rate to changes in sheet ingoing percent solids for preheated virgin linerboard sheets. Water removal rate increases rapidly as sheet moisture content increases; nip residence time is the most important secondary variable. The significance of the rapid increase in water removal rate with decreasing sheet solids can be seen in Fig. 6, where the solids out of the impulse dryer is plotted against the sheet solids into the nip. Final sheet moisture content varies by only a few percentage points whether impulse drying begins at 33 or 50% solids. The data in Fig. 6 suggest that a single impulse dryer in the third press (33% solids) position may perform equally well in terms of water removal as a long-nip third press followed by an impulse dryer (50% ingoing solids). One impulse dryer may do the work of a long nip press, plus replace a significant portion of the cylinder dryers, as well. With zone-controlled heating, an impulse dryer might also be employed for active sheet moisture profile control.

Water removal rates can be even higher for easily-dewatered furnishes such as recycled old corrugated containers and high-yield chemi-mechanical pulps. Figure 7 shows that these furnishes can have over twice the water removal of linerboard at given impulse drying conditions.

Energy Requirements

The energy requirements in BTU's per pound of water removed for preheated impulse dried linerboard sheets are shown in Fig. 8. The energy requirements are all very low relative to conventional drying performance. Similar sheets in conventional dryer

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sections would require between 3730 and 4190 kJ per kg of water evaporated (1600 and 1800 Btu/lb). The total pressure driving forces which develop during impulse drying are sufficient to remove a substantial amount of the water as liquid, reducing the energy requirement to between 1160 and 2560 kJ/kg (500 and 1100 Btu/lb) in these linerboard studies.

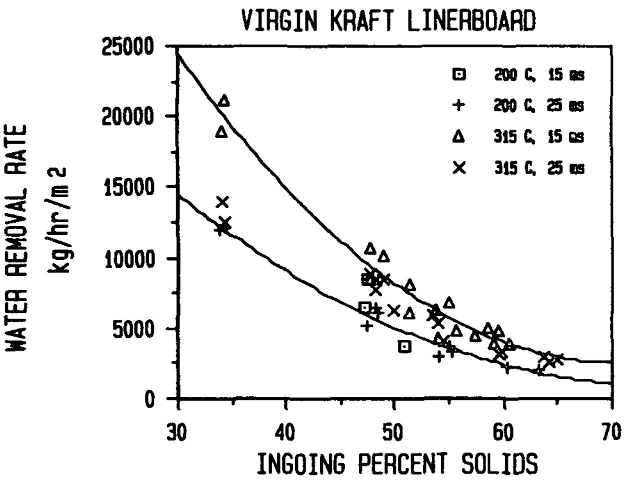

Fig. 5. The effect of sheet initial percent solids level on water removal rates for virgin kraft linerboard sheets at 127 g/m^2 preheated to 80°C before impulse drying.

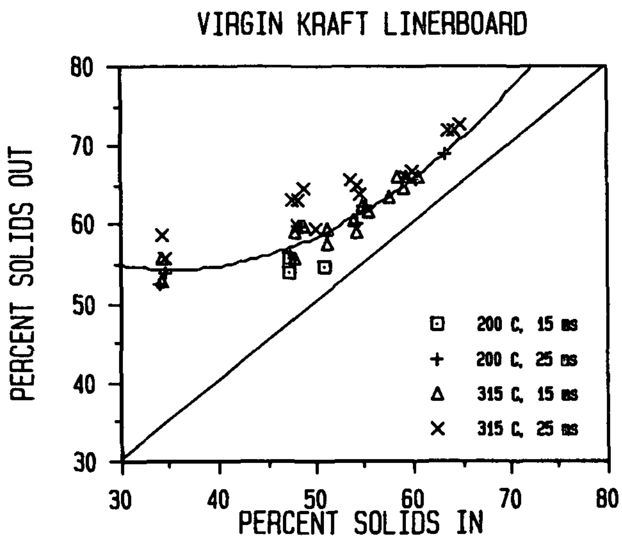

Fig. 6. The final percent solids achieved by impulse drying virgin kraft linerboard sheets at various initial solids contents. 127 g/m^2 sheets preheated to 80°C before impulse drying.

The specific energy consumption in the impulse drier nip (kJ/kg) is a strong function of ingoing sheet solids content. The rapid decline in kJ/kg requirement as sheet percent solids decreases suggests that impulse drying may be economically effective in the third-press position, although data at 33% solids and below are not yet available. Pressure, temperature, and nip residence time have weak but statistically significant effects on specific energy consumption for linerboard.

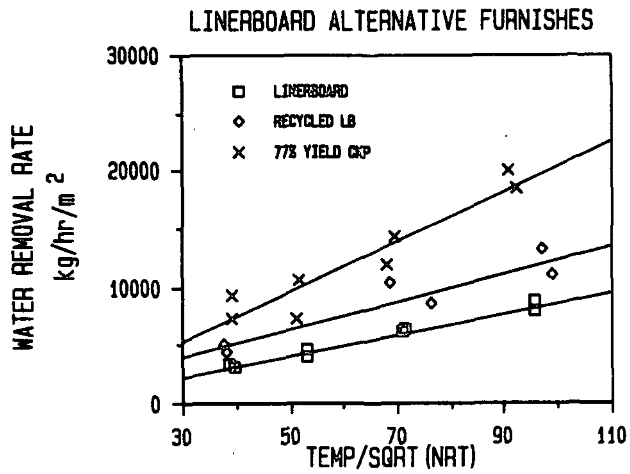

Fig. 7. Water removal rates for virgin kraft linerboard, recycled old corrugated containers and 77% yield chemimechanical pulp, all at 127 g/m^2 and 21°C initially. Impulse drying conditions ranged from 200 to 370°C, 2700 to 4800 kPa, and 15 to 30 milliseconds. TEMP = temperature, °C; SQRT(NRT) = square root of the nip residence time in milliseconds.

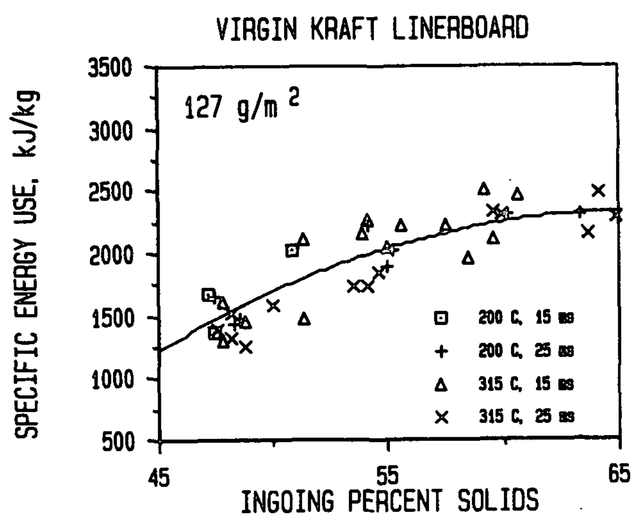

Fig. 8. Specific energy use in kJ per kg water removed for virgin kraft linerboard 127 g/m^2 sheets preheated to 80°C before impulse drying.

The excellent energy performance of impulse drying is expected to offset the increased cost of high-grade energy which will be needed to heat the process.

Development of Properties

Impulse drying produces high average density values, although the z-direction density may be nonuniform. For virgin kraft linerboard impulse dried without preheating, increases in density of up to 30% have been achieved, as shown in Fig. 9. Recycled furnishes and high-yield pulps can be even more effectively densified. All densities cited in this report are IPC densities obtained on the IPC rubber platen caliper gage (9). This method gives density numbers slightly higher than standard TAPPI densities but are used in the belief that they more accurately report the structural properties of the sheets.

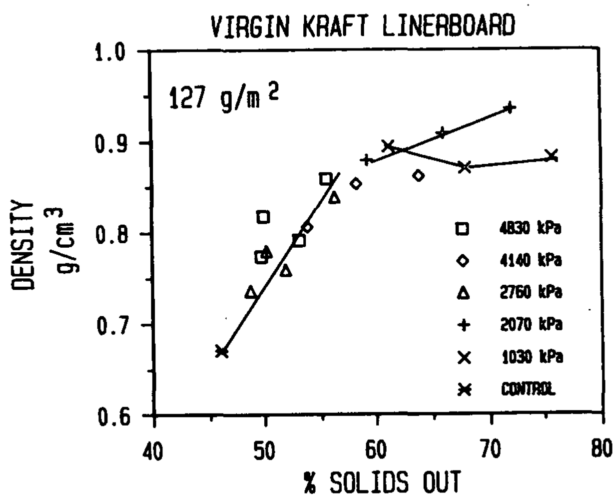

Fig. 9. Density development of virgin kraft linerboard as a function of sheet percent solids after impulse drying. Pressure has minor effects on densification above 3000 kPa.

Density varies almost linearly with the percent solids achieved during impulse drying at pressures above 2070 kPa (300 psi) (Fig. 9). At lower pressures, 1035 and 1070 kPa (150 and 300 psi), the density curves tend to flatten out, indicating that low pressures cannot sustain the densification process. There is substantial incentive to work at pressures above 2070 kPa (300 psi) if densification is the primary aim of impulse drying.

A particularly important result of these studies is the ability of impulse drying to densify high yield and recycled fiber furnishes. Figure 10 shows that impulse drying on one side of the sheet brings these weaker furnishes within the density range typical of conventional kraft linerboard; with two-sided impulse drying high-yield sheets have reached densities of 1.05 g/cm^3, exceeding conventional performance. This is significant, as the ability to substitute low strength furnishes for part of the chemical pulp requirement may have significant energy, capital, and materials savings impact on linerboard production.

These density developments translate into strength improvements, as would be expected. Tensile strength increases linearly with density for all furnishes tested (Fig. 11). Increases in virgin kraft linerboard tensile strength can approach 50%, and high-yield and recycled materials show even greater improvements. Similar increases are observed for STFI compressive strength (Fig. 12), and burst (Fig. 13). For STFI and burst, the 77% yield CMP gave better performance than virgin kraft liner at equal density values.

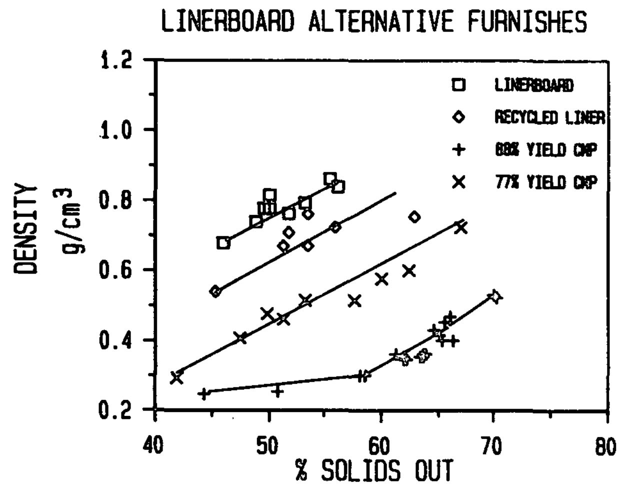

Fig. 10. Density development for virgin kraft linerboard, recycled old corrugated containers and 77 and 88% yield chemimechanical pulp, all at 127 g/m^2 and 21°C initially. Impulse drying conditions ranged from 200 to 370°C, 2700 to 4800 kPa, and 15 to 30 milliseconds.

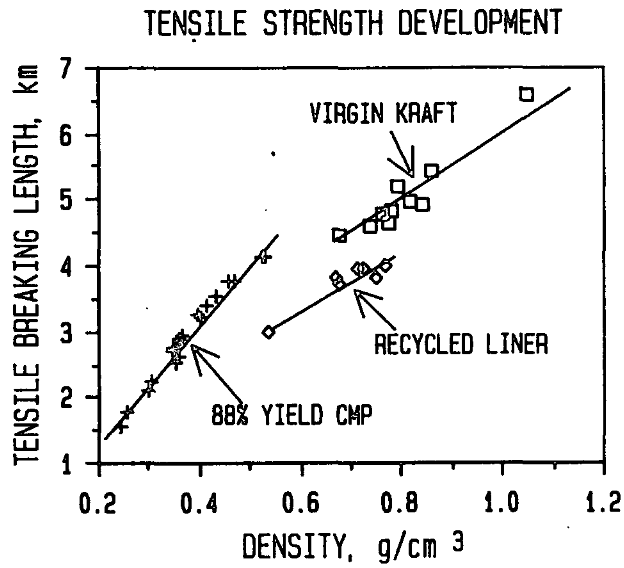

Fig. 11. Tensile strength development for several alternative linerboard furnishes.

The z-directional bonding properties of impulse dried sheets also improve with impulse drying. Figure 14 compares the z-direction tensile modulus measured by an ultrasonic technique for impulse dried virgin kraft linerboard sheets and similar sheets densified by wet pressing under room temperature conditions for very long times [up to 2 minutes pressing at 4825 kPa (700 psi)]. The impulse dried sheet has a higher z-direction modulus at a given level of densification than the cool-pressed sheets. This is evidence of more effective bonding in the impulse dried sheet due to

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the temperature effects in the sheet. The improved z-direction bonding demonstrates that impulse drying does not delaminate the sheet structure during the flash-drying portion of the nip under a wide range of conditions.

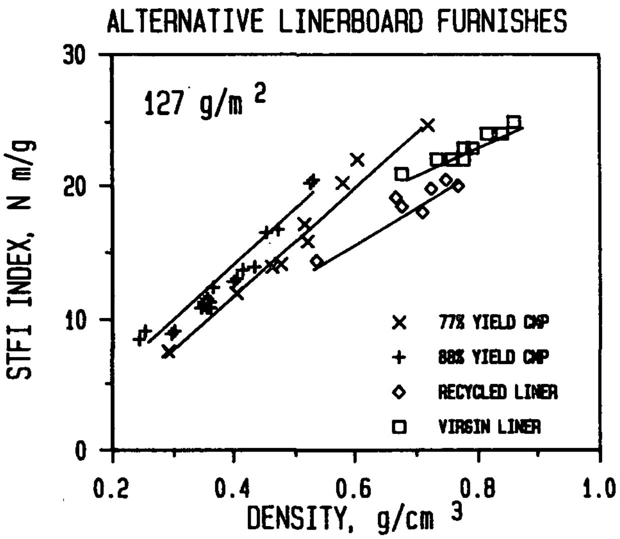

Fig. 12. STFI development with densification for several alternative linerboard furnishes.

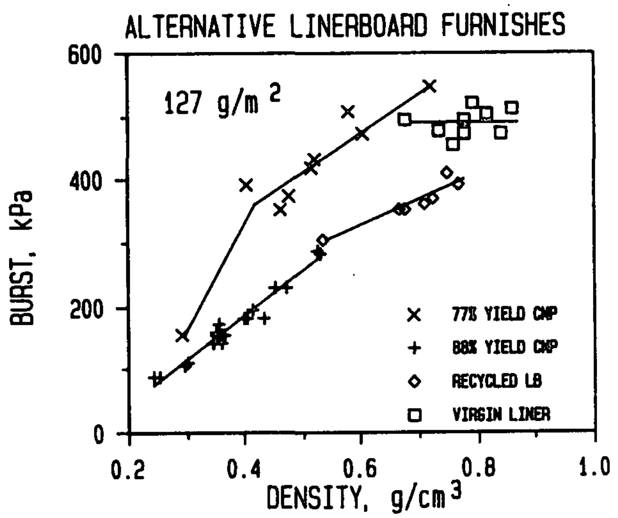

Fig. 13. Burst development with densification for several alternative linerboard furnishes.

Other Properties

Impulse drying also has significant effects on a number of properties which are expected to influence the conversion and printability of the product. In particular, surface roughness is reduced on the side of the sheet which faces the hot roll, which should improve printing quality and reduce the need for high-quality topsheet furnish. However, conversion issues such as printing quality and runnability require larger samples than those available to date. To provide such samples, a pilot roll impulse dryer is being built at The Institute of Paper Chemistry.

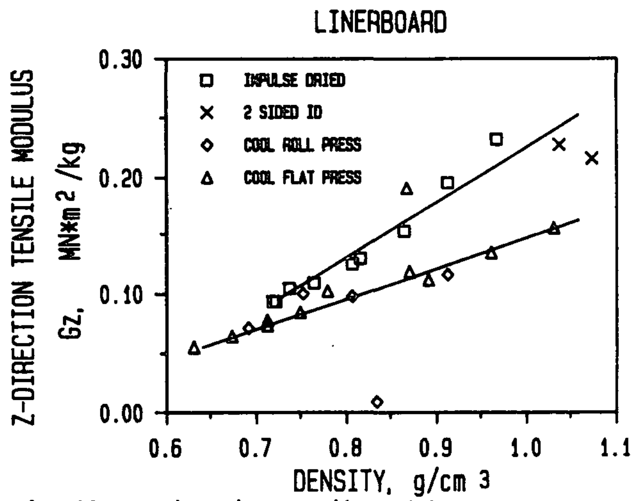

Fig. 14. Z-direction tensile modulus, measured ultrasonically as a function of density development by impulse drying and long-time, room-temperature pressing (up to 2 minutes at 4825 kPa).

This pilot equipment will be used to produce the database of semicontinuous operation and small-scale conversion necessary for further commercial development of the process. The pilot dryer will treat one-foot wide sheets; the rolls are 0.6 meter in diameter and 0.6 meter in width. Heat is supplied to the hot rolls by high-temperature electrical infrared heaters. Initial operation will be at low speeds (100 m/min), but nip conditions will accurately simulate the exposure times in high speed operation.

CONCLUSIONS

Impulse drying has dramatic and beneficial effects when applied to linerboard. High dewatering rates, 100 to 1000 times greater than those in cylinder dryers, offer the potential for equipment size reduction and capital savings, or increased throughput on existing dryer-limited machines. The low specific energy use demand, less than half that of cylinder drying under many conditions, will offset the cost of the high-grade energy required to achieve the high temperatures and heat transfer rates characteristic of impulse drying.

Impulse drying also improves sheet density and strength, particularly for recycled and high-yield furnishes. Alternative, lower cost furnishes can be brought to strength levels approaching or exceeding conventional kraft linerboard. This is very significant, as the ability to substitute recycled fiber and high-yield pulp for part of the kraft pulp while making equivalent product may have large energy, capital and materials savings potential.

Impulse drying is based on pressing and heat transfer technologies which are commercially available. The high temperature of the heated roll presents several engineering problems, but none of these appear to pose a severe obstacle to process development. Thus, it appears that impulse drying may become a practical process with the potential for making quality linerboard at reduced cost.

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The remaining development issues of pilot scale operation and the processing of samples large enough for conversion testing are currently being addressed at The Institute of Paper Chemistry.

ACKNOWLEDGMENTS

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